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Estimation of exposure to atmospheric pollutants during pregnancy integrating space–time activity and indoor air levels: Does it make a difference?

Marion Ouidir [a], Lise Giorgis-Allemand [a], Sarah Lyon-Caen [a], Xavier Morelli [a], Claire Cracowski [b], Sabrina Pontet [c], Isabelle Pin [a,d], Johanna Lepeule [a], Valérie Siroux [a], Rémy Slama [a,*]

[a] Inserm and Univ. Grenoble Alpes, IAB, Team of Environmental Epidemiology applied to Reproduction and Respiratory Health, Grenoble, France
[b] CHU de Grenoble, Clinical Pharmacology Unit, Inserm CIC 1406, Grenoble, France
[c] Air Rhône-Alpes, Lyon, France
[d] CHU de Grenoble, Pediatric department, Grenoble, France

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ABSTRACT

Studies of air pollution effects during pregnancy generally only consider exposure in the outdoor air at the home address. We aimed to compare exposure models differing in their ability to account for the spatial resolution of pollutants, space–time activity and indoor air pollution levels. We recruited 40 pregnant women in the Grenoble urban area, France, who carried a Global Positioning System (GPS) during up to 3 weeks; in a subgroup, indoor measurements of fine particles ($PM_{2.5}$) were conducted at home (n = 9) and personal exposure to nitrogen dioxide (NO_2) was assessed using passive air samplers (n = 10). Outdoor concentrations of NO_2, and $PM_{2.5}$ were estimated from a dispersion model with a fine spatial resolution. Women spent on average 16 h per day at home. Considering only outdoor levels, for estimates at the home address, the correlation between the estimate using the nearest background air monitoring station and the estimate from the dispersion model was high (r = 0.93) for $PM_{2.5}$ and moderate (r = 0.67) for NO_2. The model incorporating clean GPS data was less correlated with the estimate relying on raw GPS data (r = 0.77) than the model ignoring space–time activity (r = 0.93). $PM_{2.5}$ outdoor levels were not to moderately correlated with estimates from the model incorporating indoor measurements and space–time activity (r = −0.10 to 0.47), while NO_2 personal levels were not correlated with outdoor levels (r = −0.42 to 0.03). In this urban area, accounting for space–time activity little influenced exposure estimates; in a subgroup of subjects (n = 9), incorporating indoor pollution levels seemed to strongly modify them.

1. Introduction

Epidemiological studies have suggested adverse effects of outdoor air pollution during pregnancy on maternal and fetal health events such as pre-eclampsia, preterm birth, low birth weight, cardiac congenital malformations and intra-uterine growth retardation (Madsen et al., 2010; Pedersen et al., 2013, 2014; Salam et al., 2005; Shah and Balkhair, 2011; Slama et al., 2007a, 2007b; Vrijheid et al., 2011). This literature has some limitations, in particular in terms of exposure assessment.

Various approaches have been used to estimate exposure to atmospheric pollutants in these epidemiological studies. Many studies used air quality monitoring stations to assign exposure levels to large population, using data from the monitoring station closest to the subject's home address (Ritz and Yu, 1999). More recently, land-use regression (LUR) (Nethery et al., 2008b; Pedersen et al., 2013; Sellier et al., 2014; Slama et al., 2007a) and dispersion models (Wu et al., 2009) have been applied.

Improving the spatial resolution of exposure models may be of limited relevance if no effort is made to assess accurately where study subjects spend their time. However, so far, a person's activity throughout the day has rarely been taken into account in the exposure models used in epidemiological publications (Aguilera et al., 2009; de Nazelle et al., 2013; Nethery et al., 2014; Slama et al., 2008). Space–time activity data can be collected by interviews, diaries, as well as Global Positioning System (GPS) tracking data (Wu et al., 2010). Activity diaries are easy to implement but may suffer from recall errors, they require cumbersome post-processing by the research team (e.g., to geocode data) and do not easily allow considering exposures during commuting. GPS devices can now also be used. Advantages of using GPS devices include light weight, small size, non-obtrusive and continuous measurements (Schutz and Chambaz, 1997); the potential limitations include geolocalization errors

* Corresponding author at: Centre de Recherche Inserm-UJF U823, Institut Albert Bonniot, UJF Site Santé, BP 170, La Tronche, 38042 Grenoble Cedex 9, France.
E-mail address: remy.slama@ujf-grenoble.fr (R. Slama).

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and the fact that GPS devices often fail to record position indoors (particularly in concrete buildings) and in dense urban areas (Gerharz et al., 2013; Maddison and Ni Mhurchu, 2009), resulting in the need for a data cleaning step. GPS devices and diaries should not be opposed, but can be used simultaneously to complement each other.

Personal exposures are also greatly influenced by levels of air pollutant in indoor environments, where people from industrialized countries spend about 80% of their time (Gauvin et al., 2002; Nethery et al., 2008a). In a study of pregnant women conducted in Sabadell, Spain, personal NO_2 levels were more influenced by indoor than by outdoor NO_2 levels (Valero et al., 2009). For 24-hour measurement periods in the general population, correlations between indoor and outdoor fine particles ($PM_{2.5}$) concentrations of 0.80 and 0.68 were reported in Amsterdam and Helsinki, respectively (Brunekreef et al., 2005), while correlations of 0.63 were reported between indoor and outdoor $PM_{2.5}$ concentrations for 2-day measurements and of 0.53 for nitrogen dioxide (NO_2) concentrations for 7-day measurements among pregnant women in Barcelona (Schembari et al., 2013). Correlations may be different according to the study area, ventilation rate, and to whether one considers short or long time periods of exposure, as the contribution of temporal variations to the overall variability in exposure is smaller when longer time periods are considered.

Poor spatial resolution of environmental models, lack of consideration of space–time activity and of indoor air levels might have a strong impact in terms of exposure misclassification. However the relative contribution of these parameters to exposure misclassification has little been assessed (Brunekreef et al., 2005; Dias and Tchepel, 2014; Nethery et al., 2008b; Schembari et al., 2013). Studies simultaneously using several exposure models have demonstrated that the amplitude of the measurement error may be large (Avery et al., 2010; Lepeule et al., 2010; Nethery et al., 2008b; Sellier et al., 2014). Exposure misclassification can strongly bias estimated dose–response functions (depending on its nature) and impact statistical power (de Klerk et al., 1989).

Our objective was to compare different approaches allowing one to characterize exposure to $PM_{2.5}$ and NO_2 among pregnant women. More specifically, we compared air pollutant exposures assessed by various exposure models that differed by their ability to take into account the spatial variations of the pollutants concentrations, subjects' space–time activity and $PM_{2.5}$ indoor air levels. A secondary aim was to illustrate the impact on the estimated exposures of cleaning the GPS data used to characterize space–time activity.

2. Methods

2.1. Population sample

This study is based on *SEPAGES-feasibility* cohort (*Suivi de l'Exposition à la Pollution Atmosphérique durant la Grossesse et Effets sur la Santé*; Assessment of air pollution exposure during pregnancy and effect on health). SEPAGES is a couple-child cohort on pre- and postnatal environmental determinants of fetus and infant development and health. In the feasibility study, women with singleton pregnancy living in Grenoble were recruited in obstetrical practices before 17 gestational weeks (calculated from the date of the last menstrual period) between July 2012 and July 2013. Grenoble is a flat urban area of about 670,000 inhabitants surrounded by the Alps, with a marine West Coast climate, a warm summer and no dry season. The inclusion criteria were that women had to be 18 years old or more, speak and write French, plan to give birth in one of the four maternity wards of the Grenoble urban area, and to be enrolled in the French social security system. The study was approved by the relevant ethical committees (CPP, Comité de Protection des Personnes Sud-Est; CNIL, Commission Nationale de l'Informatique et des Libertés; CCTIRS, Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé; ANSM, Agence Nationale de sécurité du Médicament et des produits de santé). All participating women and their partners gave informed written consent for their own participation.

2.2. Study design

At each trimester of pregnancy, measurements of space–time activity and air pollution were performed for 7 consecutive days. Women were asked to carry a GPS device and filled in a detailed activity diary ($n = 40$); a subsample of women were asked to carry a NO_2 passive sampler ($n = 10$) and have a personal $PM_{2.5}$ monitor installed in their home ($n = 9$).

2.3. Space–time activity assessment

During one week at each trimester, pregnant women filled in a detailed activity diary to record their locations (home indoor/outdoor; work indoor/outdoor; other indoor/outdoor) and transport mode (Supplementary Fig. A.1). We manually geocoded the home and work addresses using the free on-line French cadastral maps (http://www.cadastre.gouv.fr/) (Jacquemin et al., 2013).

During the same three weeks, women carried a GPS device (*GlobalSat* model DG-100 for 94% of the measurement weeks, or smartphone Samsung Galaxy ACE2 with *airplane* mode turned on, which recorded their position every 30 s and 1 s, respectively). Women were asked to carry the GPS device constantly with them when they were not home.

GPS data were cleaned in three main steps: (1) cleaning based on speed: if the speed estimated between two consecutive GPS records was larger than 170 km/h (maximum speed of regional trains), the second point was considered an outlier and deleted; (2) imputation of missing data: to handle the issue of GPS not working for a duration of up to 4 h, we replaced missing data using the last non-missing coordinate, provided that the next non-missing coordinate was located within 100 m from the first next recorded location; (3) cleaning of locations close to the home address ("Home buffer"): during daytime, all points located within a 100-meter buffer from home were replaced by the home address; this distance was increased to 200 m at night. This was meant to account for the GPS signal "bouncing", which happens when the GPS device is inside a building. Moreover, when the first point of the day was inside the home buffer, we considered that the woman had spent her night at home (from midnight); similarly, if the last GPS point of the day was inside the buffer, we considered that the woman stayed home until midnight. When we did not have information for the entire night, we assumed that the woman was home from 10 p.m. to 6 a.m.

2.4. Pollutants concentrations

We considered two pollutants: $PM_{2.5}$ and NO_2. Hourly $PM_{2.5}$ and NO_2 measurements of the monitoring station closest to the volunteer's home address were used as a first approach. There were three ambient monitoring stations measuring NO_2 and one background station measuring $PM_{2.5}$ in the Grenoble urban area.

$PM_{2.5}$ and NO_2 yearly concentrations were also obtained with a finer spatial resolution by combining two dispersion models developed for the year 2012, one covering the Grenoble urban area with a fine spatial resolution (10×10 meter grid, SIRANE model), and one covering the rural areas of Rhône-Alpes region (Fig. 1), with a kilometric resolution (PREVALP model) (Soulhac et al., 2011, 2012). To obtain hourly concentrations at each location, we applied a previously defined approach relying on the hourly measurements from a background monitoring station (Lepeule et al., 2010; Pedersen et al., 2013; Slama et al., 2007a): we multiplied the yearly levels at each location by an hourly ratio C_{hourly}/C_{yearly}, were C_{hourly} and C_{yearly} corresponded to hourly concentrations and annual mean concentration respectively, both observed during the year 2012 in "Grenoble les Frênes" background station.

The same weeks the women carried the GPS device, a subsample of 10 non-smoking pregnant women carried (hanging on their bag or clothes)